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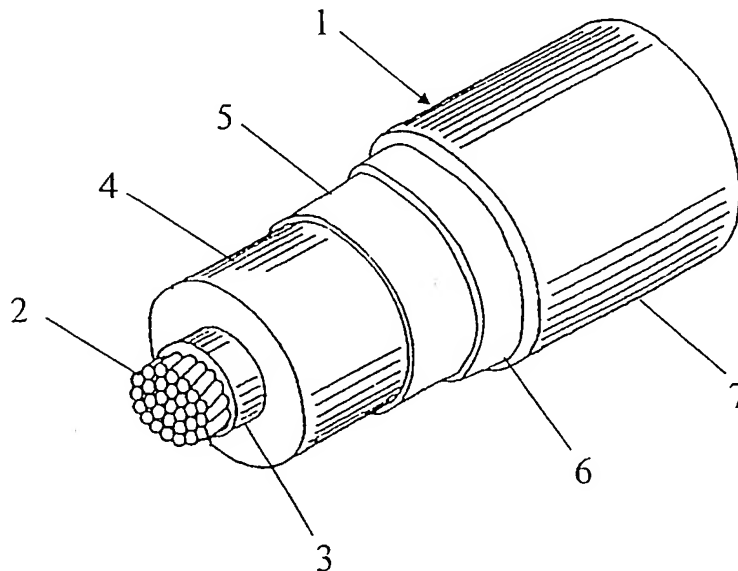
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(54) Title: CABLE WITH RECYCLABLE COVERING



(57) Abstract: The invention describes a cable with recyclable covering, particularly for transporting or distributing medium or high voltage energy, in which at least one covering layer is based on thermoplastic polymer material comprising a propylene homopolymer or a copolymer of propylene with ethylene or an  $\alpha$ -olefin other than propylene in mixture with a dielectric liquid. The cable of the invention possesses superior mechanical and electrical properties, including high dielectric strength, in particular enabling it to be used at high operating temperature.

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**CABLE WITH RECYCLABLE COVERING**

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The present invention relates to a cable with recyclable covering. In particular, the invention relates to a cable for transporting or distributing medium or high voltage electrical energy, wherein an extruded covering layer based on a thermoplastic polymer material in admixture with a dielectric liquid with high mechanical and electrical properties is present, enabling, in particular, the use of high operating temperatures and the transportation of high power energy.

The requirement for products of high environmental compatibility, composed of materials which, in addition to not being harmful to the environment both during production and utilization, can be easily recycled at the end of their life, is now fully accepted in the field of electrical and telecommunications cables.

However the use of materials compatible with the environment is certainly conditioned by the need to limit costs and, for the more common uses, guaranteeing a performance equivalent to or even better than that of conventional materials anyway.

In the case of cables for transporting medium and high voltage energy, the various coverings surrounding the conductor commonly consist of polyolefin-based crosslinked polymer material, in particular crosslinked polyethylene (XLPE), or elastomeric ethylene/propylene (EPR) or ethylene/propylene/diene (EPDM) copolymers, also crosslinked. The crosslinking, effected after the step of extrusion of the polymer material on the conductor, gives the material satisfactory mechanical performance even under hot conditions during continuous use and with current overload.

It is well known however that crosslinked materials cannot be recycled, so that manufacturing wastes and the covering material of cables which have reached the end of their life can be disposed of only by incineration.

Electric cables are also known having their insulation consisting of a multi-layer wrapping of a paper or paper/polypropylene laminate impregnated with a large quantity of a dielectric liquid (commonly known as mass impregnated cables or also oil-filled cables). By completely filling the spaces present in the multi-layer wrapping, the dielectric liquid prevents partial discharges arising with consequent perforation of the electrical insulation. As

dielectric liquids, products are commonly used such as mineral oils, polybutenes, alkylbenzenes and the like (see for example US-4,543,207, US-4,621,302, EP-A-0987718, WO 98/32137).

It is however well known that mass impregnated cables have numerous drawbacks compared with extruded insulation cables, so that their use is currently restricted to specific fields of application, in particular to the construction of high and very high voltage direct current transmission lines, both for terrestrial and in particular for underwater installations. In this respect, the production of mass impregnated cables is particularly complex and costly, both for the high cost of the laminates and for the difficulties encountered during the steps of wrapping the laminate and then of impregnating it with the dielectric liquid. In particular, the dielectric liquid used must have low viscosity under cold conditions to allow rapid and uniform impregnation, while at the same time it must have a low tendency to migrate during installation and operation of the cable to prevent liquid loss from the cable ends or following breakage. In addition, mass impregnated cables cannot be recycled and their use is limited to an operating temperature less than 90°C.

Within non-crosslinked polymer materials, it is known to use high density polyethylene (HDPE) for covering high voltage cables. HDPE has however the drawback of a lower temperature resistance than XLPE, both to current overload and during operation.

Thermoplastic low density polyethylene (LDPE) insulating coverings are also used in medium and high voltage cables; again in this case, these coverings are limited by too low an operating temperature (about 70°C).

WO 99/13477 describes an insulating material consisting of a thermoplastic polymer forming a continuous phase which incorporates a liquid or easily meltable dielectric forming a mobile interpenetrating phase within the solid polymer structure. The weight ratio of thermoplastic polymer to dielectric is between 95:5 and 25:75. The insulating material can be produced by mixing the two components while hot either batchwise or continuously (for example by means of an extruder). The resultant mixture is then granulated and used as insulating material for producing a high voltage electric cable by extrusion onto a conductor. The material can be used either in thermoplastic or crosslinked form. As thermoplastic polymers are indicated: polyolefins, polyacetates,

cellulose polymers, polyesters, polyketones, polyacrylates, polyamides and polyamines. The use of polymers of low crystallinity is particularly suggested. The dielectric is preferably a synthetic or mineral oil of low or high viscosity, in particular a polyisobutene, naphthene, polyaromatic,  $\alpha$ -olefin or silicone oil.

5 US 4410869 describes dielectric compositions comprising a mixture of ditoluyll ether isomers, optionally in the presence of hydroquinone or a derivative thereof, used for impregnating electrical devices, including capacitors and transformers.

10 US 4543207 describes dielectric compositions comprising dielectric oils and aromatic mono-olefins and/or diolefins having condensed or non-condensed aromatic nuclei. Said compositions comprise, in particular, mixtures of organic acid esters, vegetable or animal oils and aromatic ethers with 0.01-50% aromatic mono- and/or diolefins having two condensed or non-condensed aromatic rings. The compositions are used to impregnate  
15 capacitors, transformers and electric cables.

The Applicant considers as still unsolved the technical problem of producing an electric cable with a covering made from a thermoplastic polymer material having mechanical and electrical properties comparable to those of cables with an insulating covering of crosslinked material. In particular, the  
20 Applicant has considered the problem of producing a cable with a non-crosslinked insulating covering having good flexibility and high mechanical strength under both hot and cold conditions, while at the same time possessing high dielectric strength.

In view of said problem, the Applicant considers that the addition of  
25 dielectric liquids to polymer materials as proposed in the cited WO 99/13477 gives totally unsatisfactory results. In this respect, the Applicant maintains that adding a dielectric liquid to an insulating material should on the one hand determine a significant increase in its electrical properties (in particular its dielectric strength), while on the other hand maintaining the material  
30 characteristics (thermomechanical properties, manageability) unchanged, even at high operating temperature (at least 90°C and beyond).

The Applicant has now found it possible to solve said technical problem by using, as recyclable polymer base material, a thermoplastic propylene homopolymer or copolymer mixed with a dielectric liquid as hereinafter  
35 defined. The resultant composition possesses good flexibility even when cold,

excellent thermomechanical strength and high electrical performance, such as to make it particularly suitable for forming at least one covering layer, and in particular an electrical insulating layer, of a medium or high voltage cable of high operating temperature, of at least 90°C and beyond. The dielectric liquid  
5 suitable for implementing the invention has high compatibility with the base polymer and high efficiency in the sense of improving electrical performance, consequently allowing the use of small quantities of additive such as not to impair the thermomechanical characteristics of the insulating layer.

High compatibility between the dielectric liquid and the base polymer  
10 ensures homogeneous dispersion of the liquid in the polymer matrix and improves cold behaviour of the polymer.

According to a first aspect, the invention therefore relates to a cable (1) comprising at least one electrical conductor (2) and at least one extruded covering layer (3, 4, 5) based on a thermoplastic polymer material in admixture  
15 with a dielectric liquid, wherein:

- said thermoplastic material comprises a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an  $\alpha$ -olefin other than propylene, said homopolymer or copolymer having a melting point greater than or equal to 140°C and a melting enthalpy  
20 of from 30 to 100 J/g;

- said dielectric liquid comprises at least one diphenyl ether, non-substituted or substituted with at least one linear or branched, aliphatic, aromatic or mixed aliphatic and aromatic C<sub>1</sub>-C<sub>30</sub>, preferably C<sub>1</sub>-C<sub>24</sub>, hydrocarbon radical.

25 According to a first embodiment, said extruded covering layer based on said thermoplastic polymer material in admixture with said dielectric liquid is an electrically insulating layer.

According to a further embodiment, said extruded covering layer based on said thermoplastic polymer material in admixture with said dielectric liquid  
30 is a semiconductive layer.

Preferably, the propylene homopolymer or copolymer has a melting point of from 145 to 170°C.

Preferably, the propylene homopolymer or copolymer has a melting enthalpy of from 30 to 85 J/g.

35 Preferably, the propylene homopolymer or copolymer has a flexural

modulus, measured in accordance with ASTM D790, at room temperature, of from 30 to 1400 MPa, and more preferably from 60 to 1000 MPa.

Preferably, the propylene homopolymer or copolymer has a melt flow index (MFI), measured at 230°C with a load of 21.6 N in accordance with ASTM D1238/L, of from 0.05 to 10.0 dg/min, more preferably from 0.5 to 5.0 dg/min.

If a copolymer of propylene with an olefin comonomer is used, this latter is preferably present in a quantity of less than or equal to 15 mol%, and more preferably less than or equal to 10 mol%. The olefin comonomer is, in particular, ethylene or an  $\alpha$ -olefin of formula  $\text{CH}_2=\text{CH-R}$ , where R is a linear or branched  $\text{C}_2\text{-C}_{10}$  alkyl, selected for example from: 1-butene, 1-pentene, 4-methyl-1-pentene, 1-hexene, 1-octene, 1-decene, 1-dodecene and the like, or combinations thereof. Propylene/ethylene copolymers are particularly preferred.

Preferably, said thermoplastic material is selected from:

(a) a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an  $\alpha$ -olefin other than propylene, having a flexural modulus generally of from 30 to 900 MPa, preferably of from 50 to 400 MPa;

(b) a heterophase copolymer comprising a thermoplastic phase based on propylene and an elastomeric phase based on ethylene copolymerized with an  $\alpha$ -olefin, preferably with propylene, in which the elastomeric phase is present in a quantity of at least 45 wt% on the total weight of the heterophase copolymer.

The homopolymers or copolymers of class a) show a single-phase microscopic structure, ie substantially devoid of heterogeneous phases dispersed as molecular domains of size greater than one micron. These materials do not show, in fact, the optical phenomena typical of heterophase polymer materials, and in particular are characterised by better transparency and reduced whitening due to local mechanical stresses (commonly known as "stress whitening").

Particularly preferred of said class a) is a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an  $\alpha$ -olefin other than propylene, said homopolymer or copolymer having:

a melting point of from 140 to 165°C;

a melting enthalpy of from 30 to 80 J/g;

a fraction soluble in boiling diethyl ether in an amount less than or equal to 12 wt%, preferably from 1 to 10 wt%, having a melting enthalpy of less than or equal to 4 J/g, preferably less than or equal to 2 J/g;

5 a fraction soluble in boiling n-heptane in an amount of from 15 to 60 wt%, preferably from 20 to 50 wt%, having a melting enthalpy of from 10 to 40 J/g, preferably from 15 to 30 J/g; and

a fraction insoluble in boiling n-heptane in an amount of from 40 to 85 wt%, preferably from 50 to 80 wt%, having a melting enthalpy of greater than  
10 or equal to 45 J/g, preferably from 50 to 95 J/g.

Further details of these materials and their use in covering cables are given in European patent application 99122840 filed on 17.11.1999 in the name of the Applicant, incorporated herein for reference.

The heterophase copolymers of class b) are thermoplastic elastomers  
15 obtained by sequential copolymerization of: i) propylene, possibly containing minor quantities of at least one olefin comonomer selected from ethylene and an  $\alpha$ -olefin other than propylene; and then of: ii) a mixture of ethylene with an  $\alpha$ -olefin, in particular propylene, and possibly with minor portions of a diene. This class of product is also commonly known by the term "thermoplastic  
20 reactor elastomers".

Particularly preferred of the said class b) is a heterophase copolymer in which the elastomeric phase consists of an elastomeric copolymer of ethylene and propylene comprising from 15 to 50 wt% of ethylene and from 50 to 85 wt% of propylene on the weight of the elastomeric phase. Further details of  
25 these materials and their use in covering cables are given in patent application WO00/41187 in the name of the Applicant, incorporated herein for reference.

Products of class a) are available commercially for example under the trademark Rexflex<sup>R</sup> of the Huntsman Polymer Corporation.

30 Products of class b) are available commercially for example under the trademark Hifax<sup>R</sup> of Montell.

Alternatively, as thermoplastic base material, a propylene homopolymer or copolymer as hereinbefore defined can be used in mechanical mixture with a low crystallinity polymer, generally with a melting enthalpy of less than 30 J/g, which mainly acts to increase flexibility of the material. The quantity of low  
35 crystallinity polymer is generally less than 70 wt%, and preferably from 20 to



60 wt%, on the total weight of the thermoplastic material.

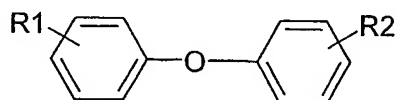
Preferably, the low crystallinity polymer is a copolymer of ethylene with a C<sub>3</sub>-C<sub>12</sub>  $\alpha$ -olefin, and possibly with a diene. The  $\alpha$ -olefin is preferably selected from propylene, 1-hexene and 1-octene. If a diene comonomer is present, this is generally C<sub>4</sub>-C<sub>20</sub>, and is preferably selected from conjugated or non-conjugated linear diolefins, such as 1,3-butadiene, 1,4-hexadiene, 1,6-octadiene or their mixtures and the like; monocyclic or polycyclic dienes, such as 1,4-cyclohexadiene, 5-ethylidene-2-norbornene, 5-methylene-2-norbornene, 5-vinyl-2-norbornene or their mixtures and the like.

Particularly preferred ethylene copolymers are:

(i) copolymers having the following monomer composition: 35-90 mol% of ethylene; 10-65 mol% of an  $\alpha$ -olefin, preferably propylene; 0-10 mol% of a diene, preferably 1,4-hexadiene or 5-ethylene-2-norbornene (EPR and EPDM rubbers fall within this class);

(ii) copolymers having the following monomer composition: 75-97 mol%, preferably 90-95 mol%, of ethylene; 3-25 mol%, preferably 5-10 mol%, of an  $\alpha$ -olefin; 0-5 mol%, preferably 0-2 mol%, of a diene (for example ethylene/1-octene copolymers, such as the products Engage<sup>®</sup> of Dow-DuPont Elastomers).

The dielectric liquid according to the invention preferably comprises at least one diphenyl ether having the following structural formula:



where R<sub>1</sub> and R<sub>2</sub> are equal or different and represent hydrogen, a phenyl group non-substituted or substituted by at least one alkyl group, or an alkyl group non-substituted or substituted by at least one phenyl.

By alkyl group it is meant a linear or branched C<sub>1</sub>-C<sub>24</sub>, preferably C<sub>1</sub>-C<sub>20</sub>, hydrocarbon radical.

Liquids advantageously usable in the present invention are for example phenyl toluyl ether, 2,3'-ditoluy ether, 2,2'-ditoluy ether, 2,4'-ditoluy ether, 3,3'-ditoluy ether, 3,4'-ditoluy ether, 4,4'-ditoluy ether, octadecyl diphenyl ether either as pure isomers or in mixture with each other. Said dielectric liquid has a ratio of number of aryl carbon atoms to number of total carbon

atoms greater than or equal to 0.4, preferably greater than or equal to 0.7.

The diphenyl ether of the invention preferably has a dielectric constant, at 25°C, of less than or equal to 8, preferably less than 4 (measured in accordance with IEC 247).

5 According to a further preferred aspect, the diphenyl ether of the invention has a predetermined viscosity such as to prevent fast diffusion of the liquid within the insulating layer and hence its outward migration, while at the same time such as to enable it to be easily fed and mixed into the polymer. Generally, the dielectric liquid of the invention has a kinematic viscosity, at  
10 20°C, of between 1 and 100 mm<sup>2</sup>/s, preferably between 3 and 50 mm<sup>2</sup>/s (measured in accordance with ISO 3104).

According to a further preferred aspect, the diphenyl ether of the invention has a hydrogen absorption capacity greater than or equal to 5 mm<sup>3</sup>/min, preferably greater than or equal to 50 mm<sup>3</sup>/min (measured in  
15 accordance with IEC 628-A).

According to a preferred aspect, an epoxy resin can be added to the dielectric liquid suitable for forming the cable of the invention, generally in a quantity of less than or equal to 1 wt% on the weight of the liquid, this being considered to mainly act to reduce the ion migration rate under an electrical  
20 field, and hence the dielectric loss of the insulating material.

The dielectric liquid suitable for implementing the invention has good heat resistance, considerable gas absorption capacity, in particular for hydrogen, and hence high resistance to partial discharges, so that dielectric loss is not high even at high temperature and high electrical gradient. The  
25 weight ratio of dielectric liquid to base polymer material of the invention is generally between 1:99 and 25:75, preferably between 2:98 and 20:80, and more preferably between 3:97 and 15:85.

Dielectric liquids of the present invention can be prepared for example by reacting a cresol, in the form of a salt of an alkaline metal, with halogen  
30 toluene possibly in the presence of a copper or copper salt-based catalyst.

Further details regarding the preparation of the dielectric liquids of the invention are reported for example in US 4410869.

According to a preferred aspect, the cable of the invention has at least one extruded covering layer with electrical insulation properties formed from  
35 the thermoplastic polymer material in admixture with the aforescribed

dielectric liquid.

According to a further preferred embodiment, the cable of the invention has at least one extruded covering layer with semiconductive properties formed from the thermoplastic polymer material in admixture with the aforescribed dielectric liquid. To form a semiconductive layer, a conductive filler is generally added to the polymer material. To ensure good dispersion of the conductive filler within the base polymer material, this latter is preferably selected from propylene homopolymers or copolymers comprising at least 40 wt% of amorphous phase, on the total polymer weight.

In a preferred embodiment, the cable of the invention has at least one electrical insulation layer and at least one semiconductive layer formed from a thermoplastic polymer material in admixture with a dielectric liquid as hereinabove described. This prevents the semiconductive layers from absorbing, with time, part of the dielectric liquid present in the insulating layer, so reducing its quantity just at the interface between the insulating layer and semiconductive layer, in particular the inner semiconductive layer where the electrical field is higher.

According to a further aspect, the invention relates to a polymer composition comprising a thermoplastic polymer material in admixture with a dielectric liquid, in which:

- said thermoplastic material comprises a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an  $\alpha$ -olefin other than propylene, said homopolymer or copolymer having a melting point of greater than or equal to 140°C and a melting enthalpy of from 30 to 100 J/g;

- said dielectric liquid comprises at least one diphenyl ether, non-substituted or substituted with at least one linear or branched, aliphatic, aromatic or mixed aliphatic and aromatic C<sub>1</sub>-C<sub>30</sub>, preferably C<sub>1</sub>-C<sub>24</sub>, hydrocarbon radical.

According to a further aspect, the invention relates to the use of a polymer composition, as described hereinabove, as the base polymer material for preparing a covering layer (4) with electrical insulation properties, or for preparing a covering layer (3, 5) with semiconductive properties.

In forming a covering layer for the cable of the invention, other conventional components can be added to the aforescribed polymer

composition, such as antioxidants, processing aids, water tree retardants, and the like.

Conventional antioxidants suitable for the purpose are for example distearylthio-propionate, pentaerithryl-tetrakis [3-(3,5-di-tertbutyl-4-  
5 hydroxyphenyl)propionate] and 1,3,5-trimethyl-2,4,6-tris(3,5-di-tertbutyl-4-hydroxy-benzyl)benzene and the like, or mixtures thereof.

Processing aids which can be added to the polymer base include, for example, calcium stearate, zinc stearate, stearic acid, paraffin wax and the like, or their mixtures.

10 With particular reference to medium and high voltage cables, the polymer materials as hereinabove defined can be advantageously used to form an insulating layer. As stated above, these polymer materials show indeed good mechanical characteristics both at ambient temperature and under hot conditions, and also show improved electrical properties, in particular they  
15 enable high operating temperature to be employed, comparable with or even exceeding that of cables with coverings consisting of crosslinked polymer base materials.

If a semiconductive layer is to be formed, a conductive filler, in particular carbon black, is generally dispersed within the polymer material in a  
20 quantity such as to provide the material with semiconductive characteristics (i.e. such as to obtain a resistivity of less than 5 Ohm.m at ambient temperature). This quantity is generally between 5 and 80 wt%, and preferably between 10 and 50 wt%, of the total weight of the mixture.

The possibility to use the same type of polymer composition for both the  
25 insulating layer and the semiconductive layers is particularly advantageous in producing cables for medium or high voltage, in that it ensures excellent adhesion between adjacent layers and hence better electrical behaviour, particularly at the interface between the insulating layer and the inner semiconductive layer, where the electrical field and hence the risk of partial  
30 discharges are higher.

The compositions of the present invention can be prepared by mixing together the base polymer material, the dielectric liquid and any other additives possibly present by methods known in the art. Mixing can be carried out for example by an internal mixer of the type with tangential rotors  
35 (Banbury) or with interpenetrating rotors, or, preferably, in a continuous mixer

of Ko-Kneader (Buss) type, or of co- or counter-rotating double-screw type.

Alternatively, the dielectric liquid of the invention can be added to the polymer material during the extrusion step by direct injection into the extruder cylinder.

5 According to the present invention, the use of the aforedefined polymer composition in covering cables for medium or high voltage enables recyclable, flexible coverings to be obtained with excellent mechanical and electrical properties.

10 Greater compatibility has also been found between the dielectric liquid and thermoplastic base polymer of the invention than in the case of similar mixtures of the same polymer material with other dielectric liquids known in the art. This greater compatibility leads, inter alia, to less exudation of the dielectric liquid and hence a reduction of the already discussed migration phenomena. Because of their high operating temperature and their low  
15 dielectric loss, the cables of the invention can carry, for the same voltage, a power at least equal to or even greater than that transportable by a traditional cable with XLPE covering.

For the purposes of the invention the term "medium voltage" generally means a voltage of between 1 and 35 kV, whereas "high voltage" means  
20 voltages higher than 35 kV.

Although this description is mainly focused on the production of cables for transporting or distributing medium or high voltage electrical energy, the polymer composition of the invention can be used for covering electrical devices in general and in particular cables of different type, for example low  
25 voltage cables, telecommunications cables or combined energy/telecommunications cables, or accessories used in constructing electrical lines, such as terminals or connectors.

Further characteristics will be apparent from the detailed description given hereinafter with reference to the accompanying drawing, in which:

30 - Figure 1 is a perspective view of an electric cable, particularly suitable for medium or high voltage, according to the invention.

In Figure 1, the cable 1 comprises a conductor 2, an inner layer with semiconductive properties 3, an intermediate layer with insulating properties 4, an outer layer with semiconductive properties 5, a metal screen 6, and an  
35 outer sheath 7.

The conductor 2 generally consists of metal wires, preferably of copper or aluminium, stranded together by conventional methods. At least one covering layer selected from the insulating layer 4 and the semiconductive layers 3 and 5 comprises the composition of the invention as hereinbefore defined. Around the outer semiconductive layer 5 there is usually positioned a screen 6, generally of electrically conducting wires or strips wound helically. This screen is then covered by a sheath 7 of a thermoplastic material, for example non-crosslinked polyethylene (PE) or preferably a propylene homopolymer or copolymer as hereinbefore defined.

The cable can also be provided with an outer protective structure (not shown in Figure 1) the main purpose of which is to mechanically protect the cable against impact and/or compression. This protective structure can be, for example, a metal reinforcement or a layer of expanded polymer as described in WO 98/52197.

Figure 1 shows only one possible embodiment of a cable of the present invention. Suitable modifications known in the art can evidently be made to this embodiment, but without departing from the scope of the invention.

The cable of the invention can be constructed in accordance with known methods for depositing layers of thermoplastic material, for example by extrusion. The extrusion is advantageously carried out in a single pass, for example by the tandem method in which individual extruders are arranged in series, or by co-extrusion with a multiple extrusion head.

The following examples illustrate the invention, but without limiting it.

#### EXAMPLES

The dielectric liquids according to the invention used in the following examples were:

- Baylectrol<sup>®</sup> 4900: ditoluyll ether (Bayer AG), dielectric constant at 25°C equal to 3.5, measured in accordance with IEC 247;

- Neovac<sup>®</sup> SY: octadecyl diphenyl ether (Matsumura Oil Research Corp.), dielectric constant at 25°C equal to 2.7, measured in accordance with IEC 247.

The comparison dielectric liquids used in the following examples were:

- Baysilone<sup>®</sup>PD5 (General Electric - Bayer), dielectric constant at 25°C equal to 2.6, measured in accordance with IEC 247;

- polyphenylmethyilsiloxane (PPMS), polyaromatic dielectric oil as described in IEEE Transactions on Electrical Insulation Vol. 26, No.4, 1991),

having a viscosity of 4 mm<sup>2</sup>/sec at 25°C;

- Flexon<sup>®</sup>641 (commercial product of Esso): naphthene-based aromatic oil having a viscosity of 22 mm<sup>2</sup>/sec at 40°C, consisting of 40 wt% aromatic hydrocarbons, 57 wt% saturated hydrocarbons and 3 wt% polar compounds.

5 As polymer materials were used:

- a flexible propylene homopolymer with melting point 160°C, melting enthalpy 56.7 J/g, MFI 1.8 dg/min and flexural modulus 290 MPa (Rexflex<sup>®</sup>WL105 - commercial product of Huntsman Polymer Corp.) (Table 1, Examples 1-6)

10 - a propylene heterophase copolymer with an ethylene/propylene elastomeric phase content of about 65 wt% (propylene 72 wt% in the elastomeric phase), melting enthalpy 32 J/g, melting point 163°C, MFI 0.8 dg/min and flexural modulus of about 70 MPa (Hifax<sup>®</sup>KSO81 - commercial product of Montell) (Table 1, Examples 7-8).

15 Composition preparation

The polymer in granular form was preheated to 80°C in a turbomixer. The dielectric liquid was added, in the quantities specified for the formulations given in Table 1, to the polymer preheated in the turbomixer under agitation at 80°C over 15 min. After the addition agitation was continued for a further hour  
20 at 80°C until the liquid was completely absorbed in the polymer granules.

After this first stage, the resultant material was kneaded in a laboratory double-screw Brabender Plasticorder PL2000 at a temperature of 185°C to complete homogenization. The material left the double-screw mixer in the form of granules.

25 Measurement of dielectric strength (DS)

The dielectric strength of the polymer compositions obtained was evaluated on test-pieces of insulating material having the geometry proposed by the EFI (Norwegian Electric Power Research Institute) in the publication "The EFI Test Method for Accelerated Growth of Water Trees" (IEEE  
30 International Symposium on Electrical insulation, Toronto, Canada, June 3-6 1990). In this method, the cable is simulated with glass-shaped test pieces of insulating material having their base coated on both sides with a semiconductive material coating.

The glass-shaped test-pieces were formed by moulding discs of  
35 insulating material at 160-170°C from a plate of thickness 10 mm obtained by

compressing granules at about 190°C.

The inner and outer surfaces of the base, which had a thickness of about 0.40-0.45 mm, were coated with a semiconductive coating. The DS measurement was made by applying to these specimens, immersed in silicone oil at 20°C, an alternating current at 50 Hz starting with a voltage of 25 kV and increasing in steps of 5 kV every 30 minutes until perforation of the test-piece occurred. Each measurement was repeated on 10 test-pieces. The values given in Table 1 are the arithmetic mean of the individual measured values.

10

TABLE 1

Ex.	Polymer	Dielectric liquid	% dielectric liquid by weight	DS (mean)
1*	Rexflex® WL 105	--	--	92
2*	Rexflex® WL 105	Baysilone® PD5	5	90
3*	Rexflex® WL 105	Flexon®641	5	94
4	Rexflex® WL 105	Baylectrol® 4900	6	140
5	Rexflex® WL 105	Baylectrol® 4900	13	152
6	Rexflex® WL 105	Neovac SY®	10	145
7*	Hifax® KS081	--	--	90
8	Hifax® KS081	Baylectrol® 4900	13	140

\* comparison

The dielectric strength values given in Table 1 highlight the improvement in electrical performance deriving from the dielectric liquids of the invention, compared to that of the base polymer as such or when mixed with the comparison dielectric liquids.

15

#### Tests on cables

Cable production:

The composition of the insulating layer and of the semiconductive layers is described in Table 2 below.



TABLE 2

	Reference cable (composition Ex 1)		Cable of the invention (composition Ex 5)	
	Insulation	Inner and outer semicond. layer	Insula- tion	Inner and outer semicond. layer
	Phr	Phr	Phr	Phr
Rexflex® WL105	100		87	
Baylectrol® 4900			13	10
Hifax® KS081		100		100
Nero Y-200		55		55
Irganox® 1330		0.3		0.3

Nero Y-200: acetylene carbon black of the firm SN2A with specific surface of 70 m<sup>2</sup>/g; Irganox® 1330: 1,3,5-trimethyl-2,4,6-tris (3,5-di-tertbutyl-4-hydroxy-benzyl)benzene (Ciba Geigy).

5 The process used for manufacturing the cable was the following. The Reflex® WL105 and the Baylectrol® 4900, this latter with previously added Irganox® 1330, were fed into a double-screw extruder (T=180°C); the mixture formed in this manner was then passed into a single-screw extruder (T=190°C, screw cross-section 150 mm<sup>2</sup>) where the filtered mixture (50 micron) feeds  
10 another extruder (screw cross-section 150 mm<sup>2</sup>, 190°C). After subsequent filtration (80 micron) the material was fed into triple head and deposited simultaneously with the semiconductive layers to form a triple layer on the metal conductor of copper plait (cross-section 400 mm<sup>2</sup>).

15 The cable leaving the extrusion head was fed into a tube containing silicone oil at 100°C and then into water where it was cooled to ambient temperature.

The finished cable consisted of a copper conductor (cross-section 400 mm<sup>2</sup>), an inner semiconductive layer of about 2 mm, an insulating layer of about 5.5 mm and finally an outer semiconductive layer of about 2 mm.

20 Under similar conditions, using the materials indicated in Table 2, a reference cable was produced.

Partial discharges:

Partial discharges were measured at 20 kV/mm without encountering currents exceeding 5 pico Columb (pC) (in accordance with IEC 60-502).

Dielectric strength:

100 metres of each of the two cables produced as described above were subjected to dielectric strength measurement based on ENEL DC4584 using alternating current at ambient temperature. Starting from 30 kV/mm the gradient applied to the cables was increased by 5 kV/mm every 30 minutes until the cables perforated. The perforation gradient considered is that on the conductor.

Table 3 summarizes the data relative to the cables and the results of the electrical tests.

10

TABLE 3

Ex.	Polymer	Dielectric liquid	% dielectric liquid by weight	DS (relative)
1*	Rexflex® WL 105	--	--	100
5	Rexflex® WL 105	Baylectrol® 4900	13	180

The results obtained indicate that the cable with additives shows a DS increase of 80% over the cable without additives.

**CLAIMS**

1. A cable (1) comprising at least one electrical conductor (2) and at least one extruded covering layer (3, 4, 5) based on a thermoplastic polymer material  
5 in admixture with a dielectric liquid, wherein:
  - said thermoplastic material comprises a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an  $\alpha$ -olefin other than propylene, said homopolymer or copolymer having a melting point greater than or equal to 140°C and a melting enthalpy  
10 of from 30 to 100 J/g;
    - said dielectric liquid comprises at least one diphenyl ether, non-substituted or substituted with at least one linear or branched, aliphatic, aromatic or mixed aliphatic and aromatic C<sub>1</sub>-C<sub>30</sub> hydrocarbon radical.
2. A cable as claimed in claim 1, wherein the propylene homopolymer or  
15 copolymer has a melting point of from 145 to 170°C.
3. A cable as claimed in claim 1 or 2, wherein the propylene homopolymer or copolymer has a melting enthalpy of from 30 to 85 J/g.
4. A cable as claimed in any one of the preceding claims, wherein the propylene homopolymer or copolymer has a flexural modulus, measured at  
20 room temperature, of from 30 to 1400 MPa.
5. A cable as claimed in any one of the preceding claims, wherein the propylene homopolymer or copolymer has a flexural modulus, measured at room temperature, of from 60 to 1000 MPa.
6. A cable as claimed in any one of the preceding claims, wherein the  
25 propylene homopolymer or copolymer has a melt flow index, measured at 230°C, of from 0.05 to 10.0 dg/min.
7. A cable as claimed in any one of the preceding claims, wherein the propylene homopolymer or copolymer has a melt flow index, measured at 230°C, of from 0.5 to 5.0 dg/min.
- 30 8. A cable as claimed in any one of the preceding claims, wherein the olefin comonomer is present in a quantity of less than or equal to 15 mol%.
9. A cable as claimed in any one of the preceding claims, wherein the olefin comonomer is present in a quantity of less than or equal to 10 mol%.
10. A cable as claimed in any one of the preceding claims, wherein the olefin  
35 comonomer is ethylene or an  $\alpha$ -olefin of formula  $\text{CH}_2=\text{CH-R}$ , where R is a linear

or branched C<sub>2</sub>-C<sub>10</sub> alkyl.

11. A cable as claimed in any one of the preceding claims, wherein the  $\alpha$ -olefin is selected from 1-butene, 1-pentene, 4-methyl-1-pentene, 1-hexene, 1-octene, 1-decene, 1-dodecene and the like, or combinations thereof.

5 12. A cable as claimed in any one of the preceding claims, wherein the thermoplastic material is selected from:

(a) a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an  $\alpha$ -olefin other than propylene, having a flexural modulus of from 30 to 900 MPa.

10 (b) a heterophase copolymer comprising a thermoplastic phase based on propylene and an elastomeric phase based on ethylene copolymerized with an  $\alpha$ -olefin, in which the elastomeric phase is present in a quantity of at least 45 wt% on the total weight of the heterophase copolymer.

13. A cable as claimed in the preceding claim, wherein the propylene  
15 homopolymer or copolymer under a) has a flexural modulus of from 50 to 400 MPa.

14. A cable as claimed in claim 12 or 13, wherein the propylene homopolymer or copolymer under a) has:

a melting point of from 140 to 165°C;

20 a melting enthalpy of from 30 to 80 J/g;

a fraction soluble in boiling diethyl ether in an amount of less than or equal to 12 wt%, having a melting enthalpy of less than or equal to 4 J/g;

a fraction soluble in boiling n-heptane in an amount of from 15 to 60 wt%, having a melting enthalpy of from 10 to 40 J/g; and

25 a fraction insoluble in boiling n-heptane in an amount of from 40 to 85 wt%, having a melting enthalpy of greater than or equal to 45 J/g.

15. A cable as claimed in any one of claims from 12 to 14, wherein the propylene homopolymer or copolymer of a) has:

30 a fraction soluble in boiling diethyl ether in an amount of from 1 to 10 wt%, having a melting enthalpy of less than or equal to 2 J/g;

a fraction soluble in boiling n-heptane in an amount of from 20 to 50 wt%, having a melting enthalpy of from 15 to 30 J/g; and

a fraction insoluble in boiling n-heptane in an amount of from 50 to 80 wt%, having a melting enthalpy of from 50 to 95 J/g.

35 16. A cable as claimed in claim 12, wherein the  $\alpha$ -olefin included in the

elastomeric phase of the heterophase copolymer under b) is propylene.

17. A cable as claimed in the preceding claim, wherein the elastomeric phase consists of an elastomeric copolymer of ethylene and propylene comprising from 15 to 50 wt% of ethylene and from 50 to 85 wt% of propylene on the weight of the elastomeric phase.

18. A cable as claimed in any one of the preceding claims, wherein the base thermoplastic material is the propylene homopolymer or copolymer in mechanical mixture with a low crystallinity polymer having a melting enthalpy of less than or equal to 30 J/g, and a quantity of less than or equal to 70 wt% on the total weight of the thermoplastic material.

19. A cable as claimed in the preceding claim, wherein the low crystallinity polymer is in a quantity of from 20 to 60 wt% on the total weight of the thermoplastic material.

20. A cable as claimed in claim 18 or 19, wherein the low crystallinity polymer is a copolymer of ethylene with a C<sub>3</sub>-C<sub>12</sub>  $\alpha$ -olefin.

21. A cable as claimed in claim 18 or 19, wherein the low crystallinity polymer is a copolymer of ethylene with an  $\alpha$ -olefin and a diene.

22. A cable as claimed in claim 20 or 21, wherein the ethylene copolymer is selected from

(i) a copolymer having the following monomer composition: 35-90 mol% of ethylene; 10-65 mol% of  $\alpha$ -olefin; 0-10 mol% of a diene;

(ii) a copolymer having the following monomer composition: 75-97 mol% of ethylene; 3-25 mol% of  $\alpha$ -olefin; 0-5 mol% of a diene.

23. A cable as claimed in the preceding claim, wherein the ethylene copolymer is selected from a copolymer having the following monomer composition: 90-95 mol% of ethylene; 5-10 mol% of  $\alpha$ -olefin; 0-2 mol% of a diene.

24. A cable as claimed in any one of claims from 20 to 23, wherein the  $\alpha$ -olefin is selected from propylene, 1-hexene and 1-octene.

25. A cable as claimed in any one of claims from 20 to 24, wherein the diene has from 4 to 20 carbon atoms.

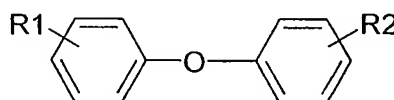
26. A cable as claimed in any one of claims from 20 to 25, wherein the diene is selected from a conjugated or non-conjugated linear diolefin, and a monocyclic or polycyclic diene.

27. A cable as claimed in any one of claims from 20 to 26, wherein the diene

is selected from 1,3-butadiene, 1,4-hexadiene, 1,6-octadiene, 1,4-cyclohexadiene, 5-ethylidene-2-norbornene, 5-methylene-2-norbornene, 5-vinyl-2-norbornene, or their mixtures and the like.

28. A cable as claimed in any one of the preceding claims, wherein the hydrocarbon radical has from 1 to 24 carbon atoms.

29. A cable as claimed in any one of the preceding claims, wherein the dielectric liquid comprises at least one diphenyl ether having the following structural formula:



where R<sub>1</sub> and R<sub>2</sub> are equal or different and represent hydrogen, a phenyl group non-substituted or substituted by at least one alkyl group, or an alkyl group non-substituted or substituted by at least one phenyl.

30. A cable as claimed in the preceding claim, wherein the alkyl group has from 1 to 20 carbon atoms.

31. A cable as claimed in any one of the preceding claims, wherein the dielectric liquid is selected from phenyl toluyl ether, 2,3'-ditolyl ether, 2,2'-ditolyl ether, 2,4'-ditolyl ether, 3,3'-ditolyl ether, 3,4'-ditolyl ether, 4,4'-ditolyl ether, octadecyl diphenyl ether either as pure isomers or in mixture with each other.

32. A cable as claimed in any one of the preceding claims, wherein the ratio of number of aryl carbon atoms to number of total carbon atoms of the dielectric liquid is greater than or equal to 0.4.

33. A cable as claimed in any one of the preceding claims, wherein the ratio of number of aryl carbon atoms to number of total carbon atoms of the dielectric liquid is greater than or equal to 0.7.

34. A cable as claimed in any one of the preceding claims, wherein the diphenyl ether has a dielectric constant, at 25°C, of less than or equal to 8.

35. A cable as claimed in any one of the preceding claims, wherein the diphenyl ether has a dielectric constant, at 25°C, of less than or equal to 4.

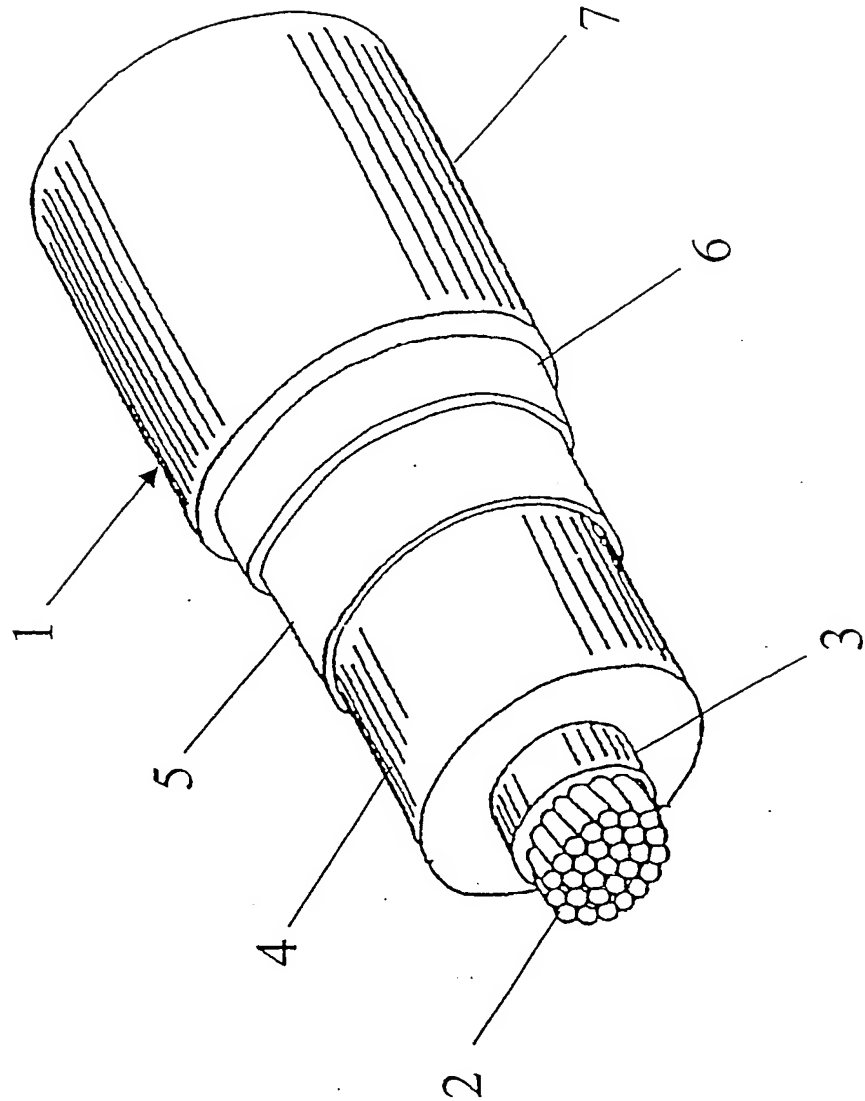
36. A cable as claimed in any one of the preceding claims, wherein the dielectric liquid has a kinematic viscosity at 20°C of between 1 and 100 mm<sup>2</sup>/s.

37. A cable as claimed in any one of the preceding claims, wherein the dielectric liquid has a kinematic viscosity at 20°C of between 3 and 50 mm<sup>2</sup>/s.
38. A cable as claimed in any one of the preceding claims, wherein the diphenyl ether has a hydrogen absorption capacity of greater than or equal to 5 mm<sup>3</sup>/min.
39. A cable as claimed in the preceding claim, wherein the hydrogen absorption capacity is greater than or equal to 50 mm<sup>3</sup>/min.
40. A cable as claimed in any one of the preceding claims, wherein an epoxy resin is added to the dielectric liquid in a quantity of less than or equal to 1 wt% on the weight of the liquid.
41. A cable as claimed in any one of the preceding claims, wherein the weight ratio of dielectric liquid to base polymer material is from 1:99 to 25:75.
42. A cable as claimed in any one of the preceding claims, wherein the weight ratio of dielectric liquid to base polymer material is from 2:98 to 20:80.
43. A cable as claimed in any one of the preceding claims, wherein the weight ratio of dielectric liquid to base polymer material is from 3:97 to 15:85.
44. A cable as claimed in any one of the preceding claims, wherein the base polymer material is selected from propylene homopolymers or copolymers comprising at least 40 wt% of amorphous phase, on the total polymer weight.
45. A cable as claimed in any one of the preceding claims, wherein the extruded covering layer is a layer (4) with electrical insulation properties.
46. A cable as claimed in any one of claims from 1 to 44, wherein the extruded covering layer is a layer (3, 5) with semiconductive properties.
47. A cable as claimed in the preceding claim, wherein a conductive filler is dispersed in the layer with semiconductive properties.
48. A cable as claimed in any one of the preceding claims, wherein at least one layer with electrical insulation properties and at least one layer with semiconductive properties are present.
49. A polymer composition comprising a thermoplastic polymer material in admixture with a dielectric liquid in accordance with any one of claims from 1 to 44.
50. Use of a polymer composition as claimed in claim 49, as base polymer material for the preparation of a covering layer (4) with electrical insulation properties.
51. Use of a polymer composition as claimed in claim 49, as base polymer

material for the preparation of a covering layer (3,5) with semiconductive properties.



Fig. 1



## INTERNATIONAL SEARCH REPORT

Int. Application No.

PCT/JP 01/09700

A. CLASSIFICATION OF SUBJECT MATTER IPC 7 H01B3/44 H01B3/22 H01B7/00		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) IPC 7 H01B H01G		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal, PAJ, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 900 766 A (KUBO MASASHIGE ET AL) 13 February 1990 (1990-02-13) column 4, line 39; claims 1,4,8,9; examples 1,2,17	1-51
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A	column 9, line 10 -column 10, line 2; claims 1-11; example 19 -- -/--	29-33
<input checked="" type="checkbox"/> Further documents are listed in the continuation of box C. <input checked="" type="checkbox"/> Patent family members are listed in annex.		
* Special categories of cited documents : *A* document defining the general state of the art which is not considered to be of particular relevance *E* earlier document but published on or after the international filing date *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) *O* document referring to an oral disclosure, use, exhibition or other means *P* document published prior to the international filing date but later than the priority date claimed *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. *Z* document member of the same patent family		
Date of the actual completion of the international search  29 October 2001		Date of mailing of the international search report  07/11/2001
Name and mailing address of the ISA European Patent Office, P.B. 5618 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 cpo nl, Fax: (+31-70) 340-3016		Authorized officer  Lehnert, A

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Inte      al Application No  
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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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